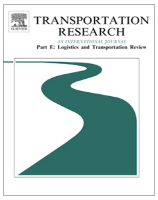
ARTICLE IN PRESS

Transportation Research Part E xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre



# A location-routing model for prepositioning and distributing emergency supplies

Aakil M. Caunhye [a], Yidong Zhang [b], Mingzhe Li [c], Xiaofeng Nie [d,*]

[a] *Department of Industrial and Systems Engineering, National University of Singapore, Singapore 117576, Singapore*
[b] *Scientific Computing Team (Asia Pacific), BASF Advanced Chemicals Co., Ltd., Shanghai 200137, China*
[c] *Faculty of Economics, Fukuoka University, Fukuoka 814-0180, Japan*
[d] *School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore 639798, Singapore*

ARTICLE INFO

*Article history:*
Received 26 August 2015
Received in revised form 21 October 2015
Accepted 27 October 2015
Available online xxxx

*Keywords:*
Emergency logistics
Risk management
Location-routing
Prepositioning
Transshipment
Distribution

ABSTRACT

We propose a two-stage location-routing model with recourse for integrated preparedness and response planning under uncertainty. The model is used for risk management in disaster situations where there are uncertainties in demand and the state of the infrastructure. We solve the two-stage model by converting it into a single-stage counterpart. The latter is then implemented in an illustrative example. Comparative analyses are run to investigate the (1) value of planning location and routing in a single model, (2) value of transshipment, (3) differences when an expected-value objective is used, and (4) value of transshipment in the expected-value model.

## 1. Introduction and literature review

The process of planning, managing, and controlling the flow of resources to provide relief to people affected by disasters is called emergency logistics (Sheu, 2007a). Since the 1950s, the number and magnitude of disasters have grown exponentially, affecting an increasing number of people (Özdamar and Ertem, 2015). As a result, emergency logistics planning has grown in complexity, with additional uncertainties to consider, coordination of operations becoming more challenging, and resource limitations becoming more pronounced. These challenges demand a rethink of the planning process.

The planning process itself extends across three major phases of the disaster life cycle: the preparedness phase, the response phase, and the recovery phase. In the preparedness phase, pre-disaster risk-mitigation operations, such as infrastructure reinforcement and inventory prepositioning, are carried out. In the response phase, immediate post-disaster relief operations are carried out. These include the location of alternative care facilities, relief commodity distribution, mass evacuation, and casualty transportation and treatment. The recovery phase is concerned with the restoration of disaster-struck systems through activities such as infrastructure repair and rebuilding and debris management. In this paper, we focus on coordinating the preparedness phase and the response phase via the integrated planning of two of their most important operations: inventory prepositioning and vehicle routing for relief distribution. The integrated planning of these processes under uncertainty is essential for combined pre- and post-disaster risk management.

---

[*] Corresponding author. Tel.: +65 6790 5641.
*E-mail address:* xiaofengnie@ntu.edu.sg (X. Nie).

http://dx.doi.org/10.1016/j.tre.2015.10.011
1366-5545/© 2015 Elsevier Ltd. All rights reserved.

Please cite this article in press as: Caunhye, A.M., et al. A location-routing model for prepositioning and distributing emergency supplies. Transport. Res. Part E (2015), http://dx.doi.org/10.1016/j.tre.2015.10.011

Traditionally, quantitative research in emergency logistics has tackled these two operations separately from each other using optimization models. For full reviews on optimization models in emergency logistics, see Altay and Green (2006), Caunhye et al. (2012) and Özdamar and Ertem (2015). Models for prepositioning alone use covering location models where inventory is located in such a way as to cover demand. Belardo et al. (1984) use a maximal covering location model to site resources for maritime oil spills. Balcik and Beamon (2008) also use a maximal covering location model to preposition relief supplies, considering multiple items with different criticalities, as well as budgetary and capacity constraints. Different from prepositioning models, vehicle routing models in the emergency logistics literature are used for planning in the response phase. Some of these models involve minor modifications of the classical vehicle routing problem (Shen et al., 2009; Vitoriano et al., 2009; Nolz et al., 2011; Vitoriano et al., 2011; Berkoune et al., 2012), such as by adding multiple commodity types, allowing split deliveries, and so on. Others integrate vehicle routing with other operations, such as pilot assignments to helicopters (Barbarosoğlu et al., 2002), scheduling (De Angelis et al., 2007), and demand clustering (Sheu, 2007b; Özdamar and Demir, 2012).

The models discussed above all address either preparedness issues or response issues, but not both. For proper coordination, planning for these two disaster phases must be coordinated. Even when emergency logistics models bring coordination to the forefront by planning prepositioning and relief distribution in tandem, they use location-allocation frameworks where the prepositioning of inventory is accompanied with a resource allocation plan to satisfy demands when disaster strikes. Duran et al. (2011) devise a typical location-allocation model where warehouse locations and inventory levels are decided, and resources are allocated to regional demand locations. In Rennemo et al. (2014), a three-stage stochastic programming model is used, where the first stage performs facility location and inventory prepositioning and the next two stages perform relief distribution. The second stage considers uncertainty in available supplies and vehicles, whereas the third stage considers uncertainty in the state of infrastructure. While the authors include vehicle usage for relief distribution in stages two and three, they do not perform route construction, but rather node-to-node allocation of vehicles and commodities. The works by Ukkusuri and Yushimito (2008) and Mete and Zabinsky (2010) factor in routing considerations. In Ukkusuri and Yushimito (2008), supplies are prepositioned while accounting for possible disruptions in the transportation network. The approach uses a combination of the most reliable path and an integer programming model to find the optimal location of supplies. In Mete and Zabinsky (2010), a two-stage stochastic programming approach is used, where the first stage performs medical supplies prepositioning and the second stage devises resource allocation plans under uncertainty. The allocation plans are then converted to detailed vehicle assignments and routing. This work is the only model we have found that integrates supplies prepositioning and vehicle routing. However, prepositioning and routing are planned separately.

Unfortunately, approaches whereby location and routing are separately planned lead to suboptimal solutions (Salhi and Rand, 1989). To avoid suboptimality, a location-routing model must be used. The concept of such a model is not new and has existed since the late 1980s. Early location-routing papers have limited capacity considerations for routes and depots. They either consider capacitated routes or capacitated depots, but not both (Laporte et al., 1988; Chien, 1993) or do not consider any route or depot capacities (Tuzun and Burke, 1999). With time, most location-routing papers have added capacity constraints for both routes and depots, formulating what is now commonly known as the capacitated location-routing problem. In this paper, we use a two-stage capacitated location-routing model with transshipment considerations for integrated prepositioning and relief distribution planning under uncertainty. In the first stage, the model sets up warehouses and determines their inventory levels. In the second stage, the model plans transshipment quantities, delivery quantities, and vehicle routes for every scenario of uncertainty realization. Because of the nature of disasters, the second stage also allows unmet demands. The model has the objective of minimizing the weighted sum of the total preparedness cost and the worst-case total response time among all scenarios of uncertainty realization. Two-stage models with recourse are traditionally built as stochastic programming models where the expected value of the second-stage objective is used. One difficulty with using the expected value is that it requires estimates of the probabilities of occurrence of the different scenarios. Secondly, the solution can be sensitive to the choice of the probability distribution. The probability distribution of possible scenarios is hard to estimate, especially for disasters. Infrastructure is constantly being improved, in part in response to previous disasters. Moreover, because of global warming, extreme disasters are becoming more frequent. The next disaster typically differs significantly from historical patterns, which makes probability distributions based on historical data all the more unreliable. By choosing to optimize the worst-case total response time, we bypass the need for probabilities of occurrence of scenarios.

The literature on multi-stage location-routing models is scare, no less due to the tractability of such models. Deterministic location-routing models are themselves *NP*-hard (Tuzun and Burke, 1999). The multi-stage models we have found in the literature are in the form of two-stage stochastic location-routing models, with probability distributions assumed for customer demands and supplies. Laporte et al. (1989) build a two-stage stochastic location-routing model where vehicles are routed from depots to collect supplies from customers. In the first stage, the model locates depots, determines the fleet size, and plans the routing prior to customer supply values being known. In the second stage, customer supply values become known and recourse actions are taken in such a way that if the total customer supply along a route exceeds the vehicle capacity, the vehicle is routed back to the depot to empty its load before resuming its journey. Albareda-Sambola et al. (2007) also construct a two-stage stochastic location-routing problem with recourse in which the presence or absence of service request of the customers is not known a priori. In this model the locations of plants and the choice of routes are carried out prior to uncertainty realization. Routes are chosen assuming customers have random demands. Because of that, after uncertainty realization, the total demand along a route may exceed the vehicle capacity. Recourse actions are therefore taken in the

Please cite this article in press as: Caunhye, A.M., et al. A location-routing model for prepositioning and distributing emergency supplies. Transport. Res. Part E (2015), http://dx.doi.org/10.1016/j.tre.2015.10.011